

# Multi-energy radiography on the basis of “scintillator-photodiode” detectors

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## Abstract

For reconstruction of the spatial structure and thicknesses of complex objects and materials, it is proposed to use multi-radiography with detection of X-ray or gamma-radiation by combined detector arrays of scintillator-photodiode type. Experimental studies have been carried out of the energy dependence of sensitivity of dual-energy inspection systems based on scintillators  $ZnSe(Te)$  and  $CsI(Tl)$ .

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## 1 Introduction

The digital radiographic method is one of the main directions of modern industrial non-destructive testing (NDT), e.g., [1]. Technical diagnostics (TD) are based on scanning (linear or planar) and subsequent topography of the three-dimensional structure of the object. It is often needed to carry out quantitative analysis of the internal structure of materials. When the geometry is complex, as well as for systems of variable thickness, multi-layered, multiply connected or multi-component structure, conventional NDT methods could be insufficient. The use of more informative and more complex tomographic methods is not always possible due to technical or economical reasons. Important progress can be achieved here in relationship with a multi-energy radiography (MER). Monitoring with separate detection of radiation at several energies can give additional information on the internal structure of the studied object. A block diagram of such method is presented in fig. 1.

## 2 MER Thickness Reconstruction

In developing of the said aspect of MER, especially efficient are simple schemes of two- and three-energy monitoring. It follows from the theory that the number of reconstructed thicknesses is the same as the multiplicity of radiography, i.e., the number of separately detected radiation ranges. Consequent local scanning of the object allows us to reconstruct the profile of its internal three-dimensional structure

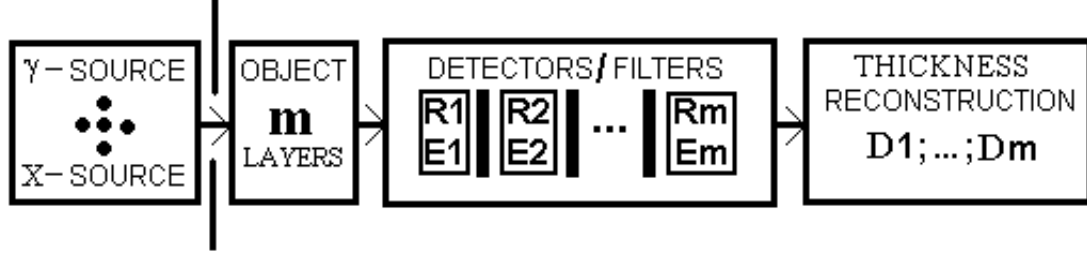


Figure 1: Schematic diagram of multi-energy radiography of thickness (defects).

also in the case of variable cross-section of the components that form it. To determine thickness of separate components or size of inclusions of each specific material, one has to assume their effective atomic number  $Z$  and density  $\rho$  to be approximately known. Or, linear attenuation coefficients should be specified for corresponding substances. For independent determination of these  $Z$  and  $\rho$ , it is also possible to use means of MER [2]. Theoretical model for thickness reconstruction by means of MER uses the universal character of exponential attenuation of the radiation in objects and detectors. Passing over to logarithmic units of the detected signal normalized to the background value (when the object is absent), radiography equations can be presented in a simple form

$$R_i = \sum_{j=1}^M \mu_{ij} D_j ; \quad i = 1, \dots, m ; j = 1, \dots, M \quad ; \quad (1)$$

where  $\mu_{ij} = \rho_j [\tau(E_i) Z_j^4 + \sigma(E_i) Z_j + \chi(E_i) Z_j^2]$  and  $R(E_i) \equiv R_i$  are reflexes (registration data) at corresponding maximum absorption energies within each monitoring range. Unknown are thicknesses  $D_i$ . Matrix  $\mu_{ij}$  (of linear attenuation coefficients) will be specified, with energy dependencies on photo-effect  $\tau$ , Compton scattering  $\sigma$  and pair generation effect  $\chi$ . In the medium energy range up to  $0.5 \text{ MeV}$ , the latter scattering channel can be neglected. Solving the linear system (1) is the inverse problem of MER. To obtain its unique solution the number of layers  $m$  should correspond to the order  $M$  of multiplicity,  $m = M$ . The general solution has the form

$$D_i = \sum_{j=1}^m \mu_{ij}^{-1} R_j ; \quad \det \mu_{ij} \neq 0 \quad , \quad (2)$$

where  $\mu_{ij}^{-1}$  is the inverse matrix. In the case of 2-MER

$$D_1 = \frac{\mu_{22} R_1 - \mu_{12} R_2}{\mu_{11} \mu_{22} - \mu_{12} \mu_{21}} ; \quad D_2 = \frac{\mu_{11} R_2 - \mu_{21} R_1}{\mu_{11} \mu_{22} - \mu_{12} \mu_{21}} \quad . \quad (3)$$

In the general case, for determination of  $D_i$  it is necessary and sufficient that determinant  $\det \mu_{ij} \neq 0$ . This implies a physical condition for MER feasibility:

$$\text{for all } i \neq j \implies |E_i - E_j| \gg \delta E_{noise} \quad , \quad (4)$$

where  $\delta E_{noise}$  is the total noise level in the system expressed in energy units. For one-energy radiography, separation of the reconstructed “images” of the complex object by scanning at one camera angle is not possible. This experimentally and theoretically proven fact corresponds to the uncertainty of expressions (3) when their denominator becomes zero at  $E_1 = E_2$ .

### 3 Sensitivity of Multi-Radiography

For practical developments of the MER, an important factor are detector sensitivity,  $S = dR/dD$ , and relative sensitivity,  $T = \delta/D$ , of the inspecting system. Here  $\delta$  is the minimum wire thickness that could be detected on the main detection background (accounting for noises);  $D$  is the fixed thickness of the tested sample. As it follows from Eqs. (2)–(3)

$$S \propto [K(E) \mu(E)] ; \quad T \propto \frac{\text{const}}{K(E) \mu(E) D} \quad \Longrightarrow \quad S \sim T^{-1} . \quad (5)$$

where  $K(E)$  – conversion efficiency of the detectors. In the Concern “Institute for Single Crystals”, combined detectors of “scintillator-photodiode” type have been developed, which are characterized by improved detector sensitivity. In assemblies of 2-radiography, tellurium-doped zinc selenide  $ZnSe(Te)$  is used as scintillator for the low-energy detector (LED). For the high-energy detector (HED) scintillator  $CsI(Tl)$  is used.  $ZnSe(Te)$  has lower effective atomic number,  $Z_L = 32$ , as compared with cesium iodide,  $Z_H = 54$ , but its density is high enough to ensure efficient absorption of the radiation in the low energy region. This allows its use not only as a detector, but also as an energy filter cutting off the low-energy part of the spectrum. Efficiency of such filter with photo-effect is not less than  $\propto (1 - (Z_L/Z_H)^4) \approx 88\%$ . Light output of  $ZnSe(Te)$  can reach 100 – 130% with respect to  $CsI(Tl)$  at absorbing thickness of 0.1 – 1.0 mm. Optimum thickness values of scintillators for the 2-MER with  $U_a = 140 \text{ kV}$  are: for LED  $ZnSe(Te)$  – 0.6 mm; for HED  $CsI(Tl)$  – 4 mm. As a result, all this ensures substantial advantages of zinc selenide for radiation detection in the 20 – 80 keV range as compared with other scintillators. Fig. 2 show results of our measurements of the detecting sensitivity  $S$  for with various combined scintielectronic detector arrays. The data obtained confirm advantages of the chosen design of the dual-energy inspection system.

### 4 Conclusions

The developed scheme of MER can be directly used for different control evaluations, especially in topography of several surimposed “layers”(or defects) or when analysis under different camera angles is impossible. Quantitative determination of thicknesses in a many-component structure makes it possible to physically discern between physically surimposed parts of one and the same piece of object. This substantially increases contrast sensitivity of MER as compared with conventional methods, which is important not only for technology, but also for medical applications.

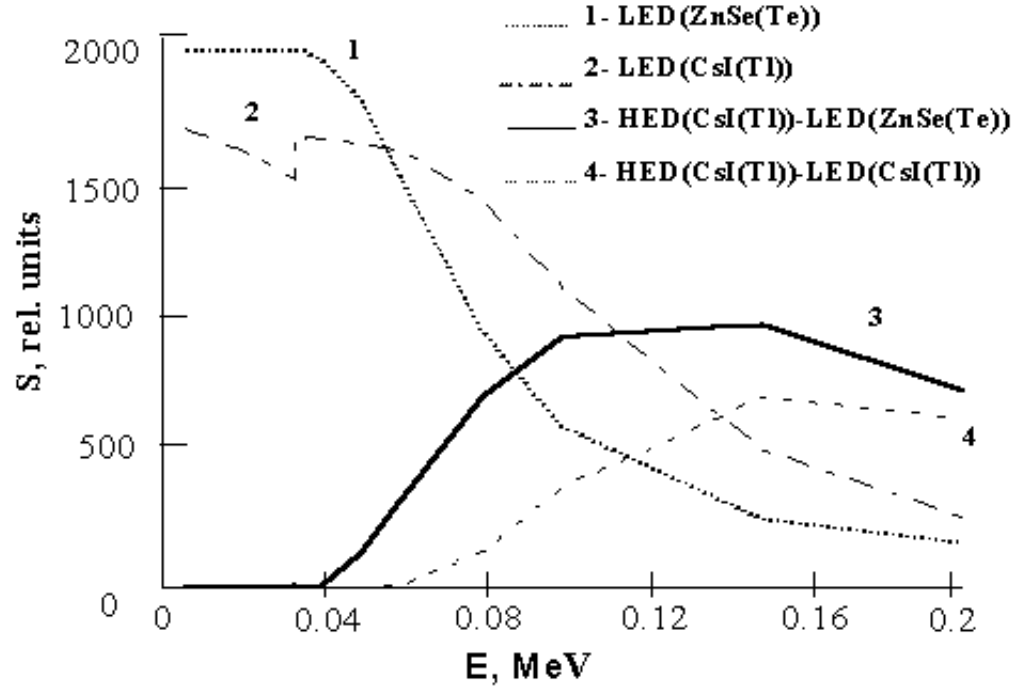


Figure 2: Energy dependence of detector sensitivity of two-level inspection systems. The X-ray source used had anode voltage  $U_a = 40 - 180 \text{ kV}$  and current  $I_a = 0.4 \text{ mA}$ .

## References

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